Amorphous Al Alloys: An AF Perspective

DARPA Structural Amorphous Metals Initiative
Bidders Conference
6 June 2000

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OUTLINE

AF REQUIREMENTS

- High Specific Strength and Stiffness
- Elevated Temperature
- Affordability

POTENTIAL APPLICATIONS

CHARACTERISTICS OF AMORPHOUS AL

TECHNOLOGY ISSUES

CONCLUDING REMARKS

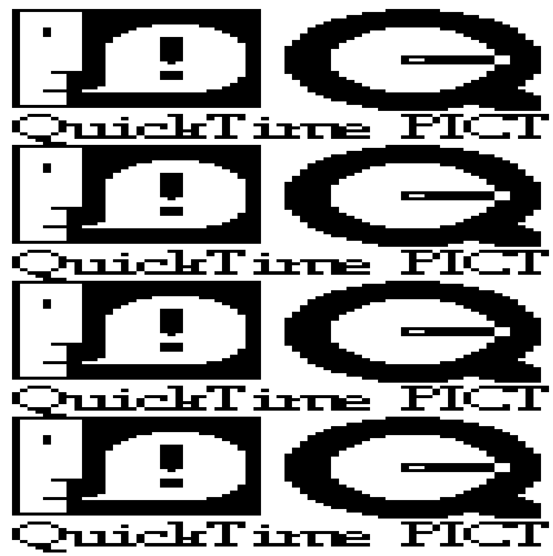
SPECIFIC STIFFNESS, STRENGTH

Stiffness and strength are the primary design factors in nearly every aerospace structure

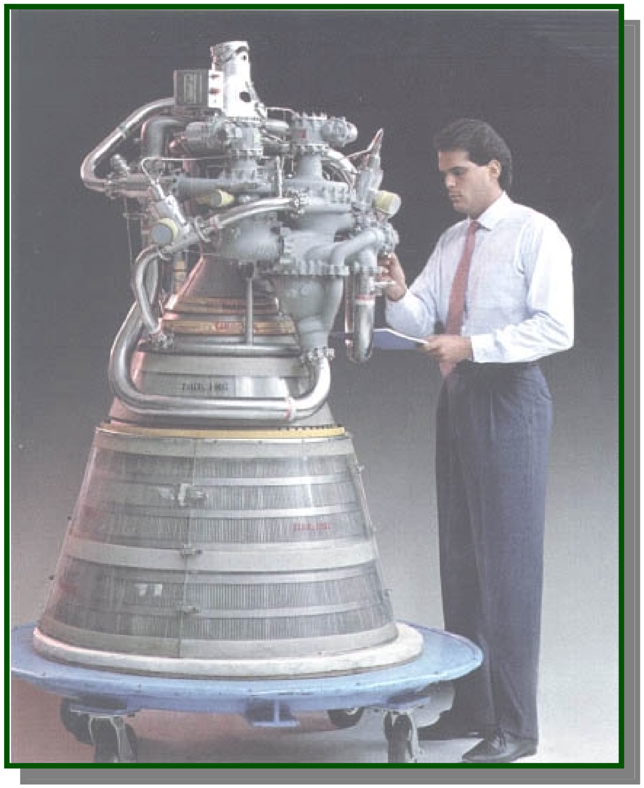
- controls size and spacing of structural members
- reduces deflections
- defines vibrational frequencies
- controls onset of instabilities and failure (buckling, crippling, shear . . .)
- fatigue response often scales with stiffness

Higher specific properties provide improved resistance to elastic / plastic deformation at reduced mass

- especially important for dynamic parts and systems
  - ✓ payload for geosynchronous earth orbit is usually ~1% of launch mass



LIQUID ROCKET PROPULSION REQUIREMENTS



Major advancements in performance and affordability are controlled by specific strength

- Most major static and dynamic components are limited by specific strength
- Ni alloys, stainless steel widely used in current systems

Metallic materials offer significant advantages

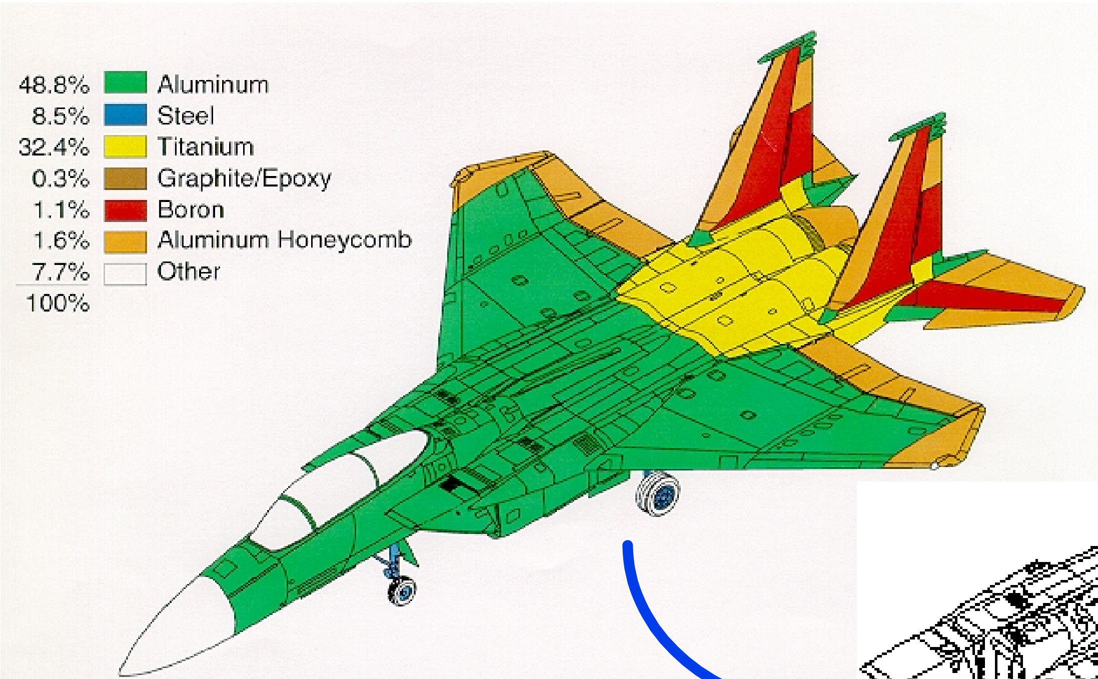
- affordable materials and manufacturing
- resistance to cryogens

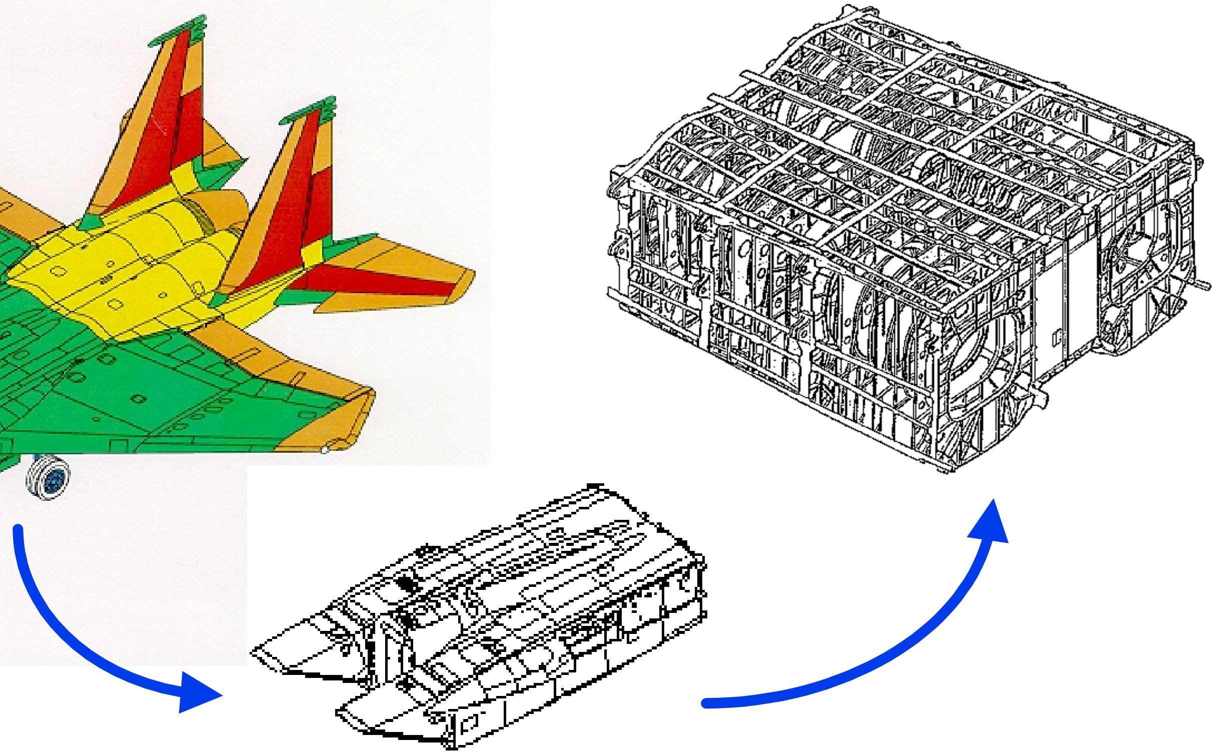
Candidate components include:

- pump and turbine housings
- pump and turbine impellers
- lines, ducts and bellows

Materials for liquid rocket propulsion is a major AF initiative (IHPRPT)

AIRFRAME CONSTRUCTION

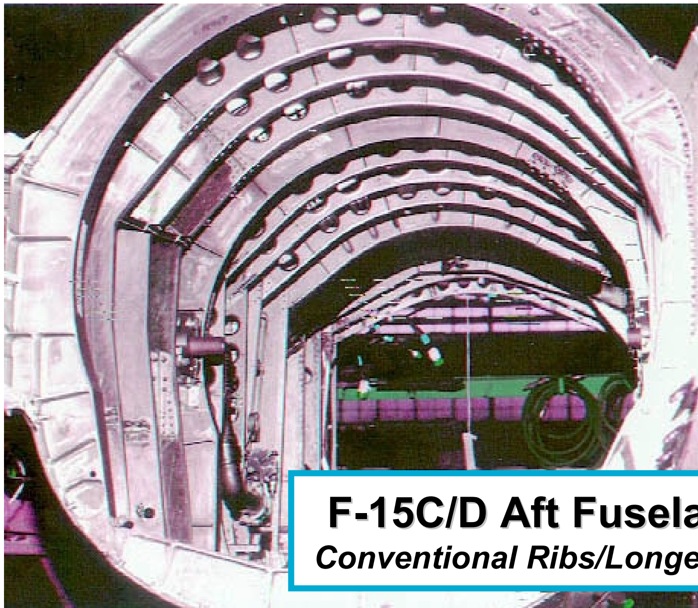




Skin/stringer construction is inefficient

— low E/ρ requires close spacing of support structure
— joints do not transfer loads efficiently
— many simple detail parts require expensive assembly operations

AIRFRAME AFFORDABILITY



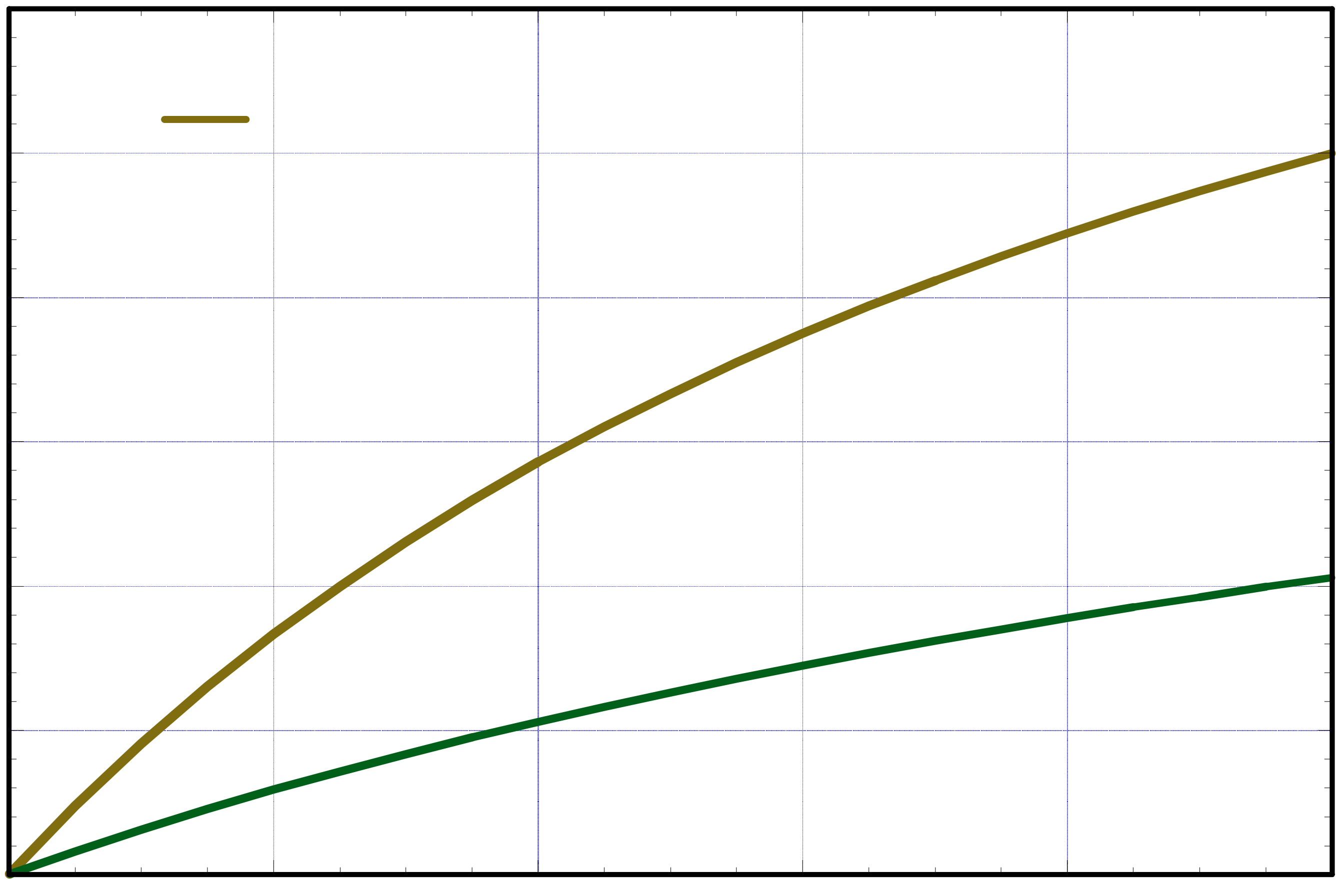
F-15C/D Aft Fuselage
Conventional Ribs/Longerons

F-15E Aft Fuselage
SPF/DB Stiffened Panels

SPF/DB panels replace skin/stringer assembly
— 726 part details and 10,000 fasteners eliminated
— significant cost reduction at the assembly level

More expensive materials can provide significant cost savings at the assembly/system level if properly integrated through collaborative design

IMPACT OF SPECIFIC PROPERTIES



ELEVATED TEMPERATURE Al

Explore systems with potential for moderate improvement in maximum use temperature

- goals for maximum use temperature are 200°C (~400°F) and 300°C (~575°F)
  - lower T for aerostructures, aeropropulsion and rocket propulsion (except turbine)
  - higher T for aeropropulsion and rocket propulsion (turbine)
- replace Ti components and OMC's which are currently overspecified

Opportunities exist in new aerospace systems

- Unmanned Air Vehicles (UAV)
- Advanced cruise missiles
- Joint Strike Fighter (JSF)
- Integrated High Payoff Rocket Propulsion Technology (IHPRPT)

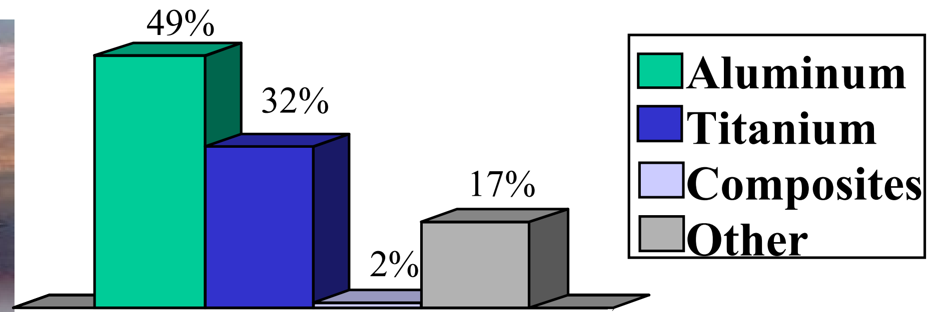
Technical challenges

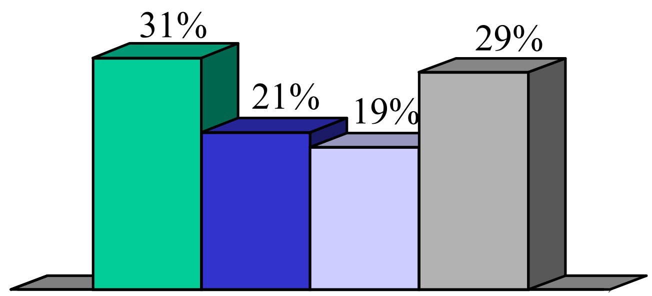
- high specific strength required
- ensure adequate fracture toughness remains *(the major technical challenge!)*
- focus on affordable processing that is consistent with the material approach
- full life applications require very stable systems

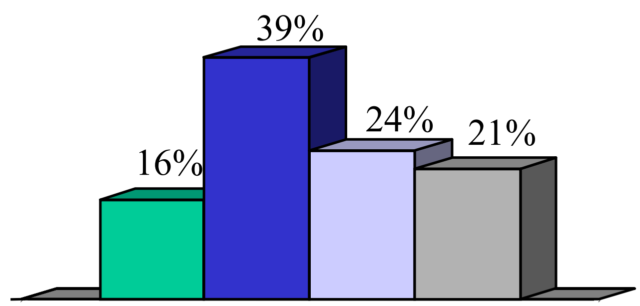
Structural Amorphous Aluminum

Provides A New Design Alternative For Aerospace System Designers

1987





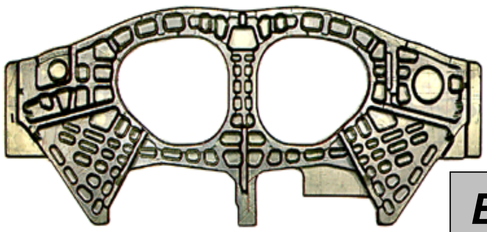


present

Affordability Is Now Being Emphasized When Selecting Airframe Materials

AIRFRAME SUBCOMMITTEE REPORT

Sagamore Workshop on Cost Reduction (1972)



Buy-to-Fly 22:1

Airframes are expensive because:

- large number of detail parts and subassemblies
- lot of holes & fasteners *(1M rivets in Boeing 747!)*
- large number of man-hours to assemble details per pound of structure

30-70% of manufacturing cost for subassembly and assembly man-hrs

- manufacturing hours are directly proportional to:
  - ✓ number of detail parts and number of holes for joining
  - ✓ number & type of fasteners required
- 10%-22% of manufacturing man-hours are due to quality assurance

10%-50% of finished product cost is due to material cost

- very high buy-to-fly ratio for large frames and bulkheads

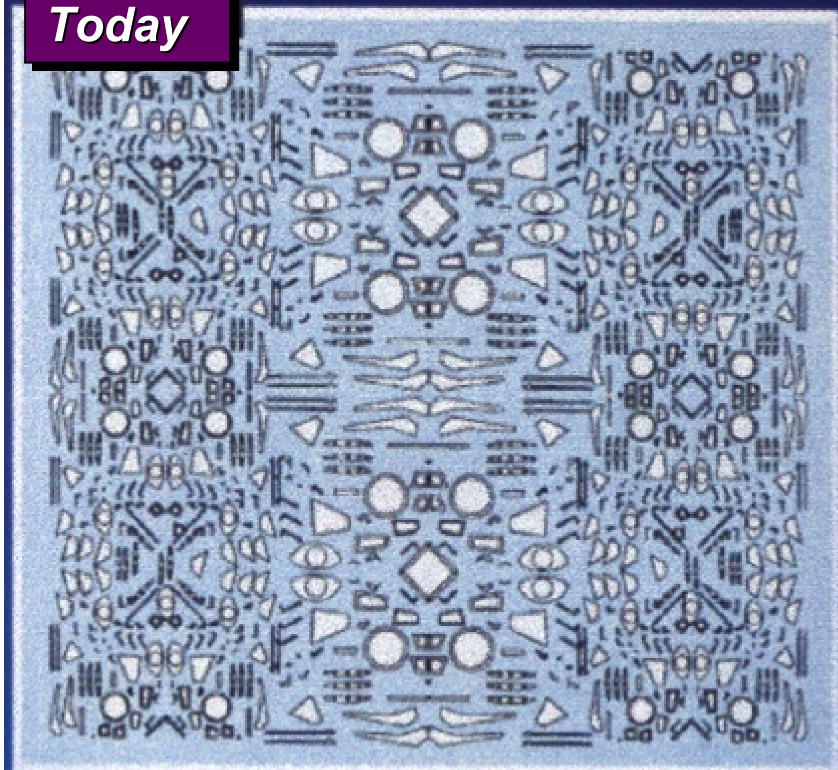
Reduced part count, holes, fasteners provides significant cost reduction

- unitized design and manufacturing is a major cost-reduction methodology
  - ✓ requires improved machining or near net shape technologies
  - ✓ large wrought or cast product required

Composites Affordability Initiative

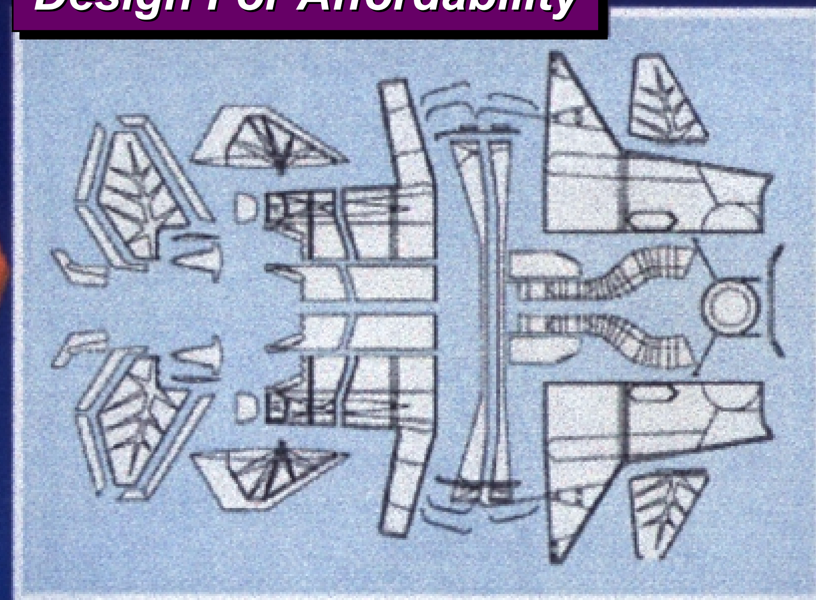
OUR VISION

Today



- 11,000 Metal Components
- 600 Composite Components
- 135,000 Fasteners

Design For Affordability



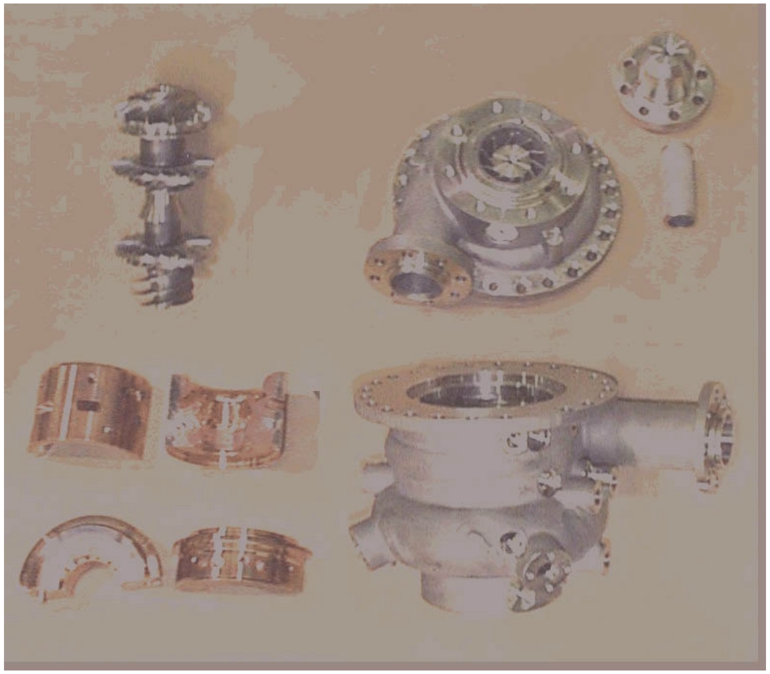
- 450 Metal Components
- 200 Composite Components
- 6,000 Fasteners

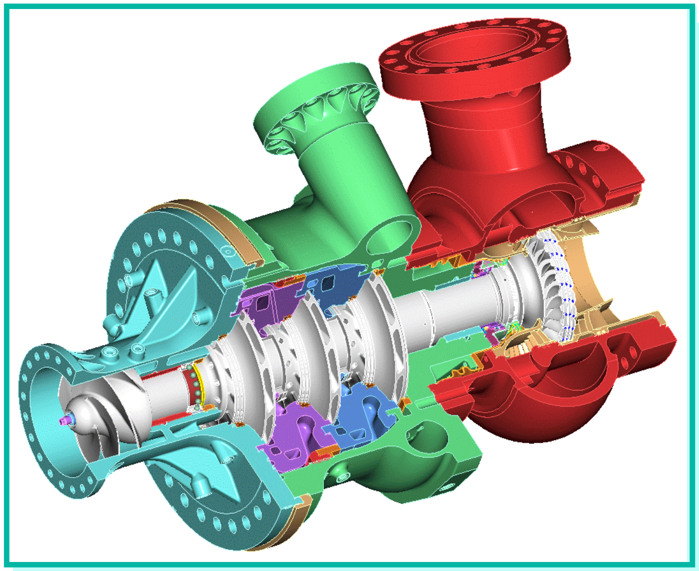
- *Reduce Part Count*
- *Improve Producibility*
- *Dramatically Reduce Assembly Costs*

BOEING LOCKHEED MARTIN NORTHROP GRUMMAN

Advanced LH_2 Turbopump

Metals Enable Simplified Design





- ***Sophisticated manufacturing and design, improved material properties enable reduced part count and cost***
- ***Single piece rotor with unshrouded impellers and radial turbine***

Integrated Powerhead Design

Part Count = 524 pieces

(SSME = 1433 pieces)

SUMMARY OF AF REQUIREMENTS

High specific strength and stiffness

- improved structural efficiency for significant decrease in system weight
- enables significant part count reduction for affordability
- metallic materials can replace organic composites with significant improvement in system cost and supportability
- enables new methodologies for systems design and construction
  - ✔ unitized construction for affordability
  - ✔ expanded design opportunities for new systems, such as UAV

Al alloys with elevated temperature capability

- long-held goal for AF with broad applicability and high payoff
- replace many Ti and OMC components, providing significant savings in both cost and system weight

Affordability

- underlies every major system requirement
- advanced (more costly) materials can provide cost reductions at the assembly/system level
  - ✔ requires materials / design partnership

OUTLINE

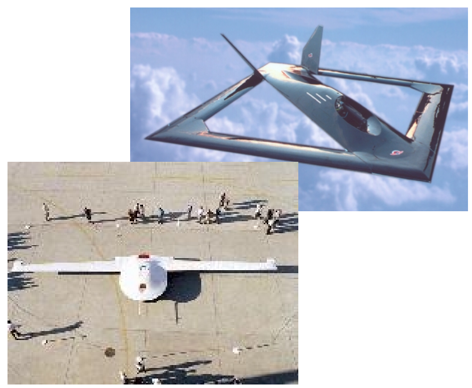
- AF REQUIREMENTS
- POTENTIAL APPLICATIONS
  - Aerostructures
  - Aeropropulsion
  - Liquid Rocket Propulsion
- CHARACTERISTICS OF AMORPHOUS AL
- TECHNOLOGY ISSUES
- CONCLUDING REMARKS

AIR VEHICLES DIRECTORATE
S&T Focus: Integrating Concepts

Sustainment:
Technology insertion to enable today's fleet to meet tomorrow's warfighter needs

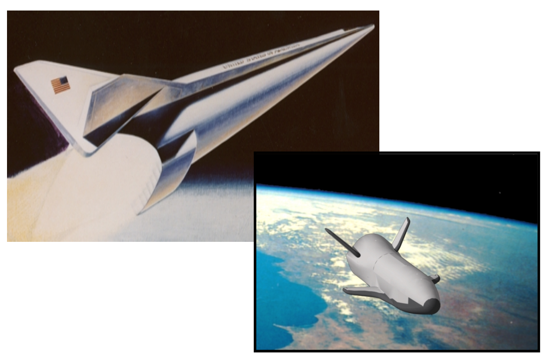
- Increased mission capable rates
- Reduced operation and support costs

Unmanned Air Vehicles:
Technologies to enable routine operation of high payoff UAV alternatives across the full spectrum of warfare



- Seamless manned / unmanned vehicle operation
- Superior mission capability at reduced cost
- Intelligent control of UAV swarms

Space Access & Future Strike:
Affordable space access and quick reaction trans-atmospheric capability



- Aircraft like operation -- quick turnaround and flexible mission capability
- Global engagement in less than 3 hours
- Reduced cost for access to space

Unmanned Air Vehicles

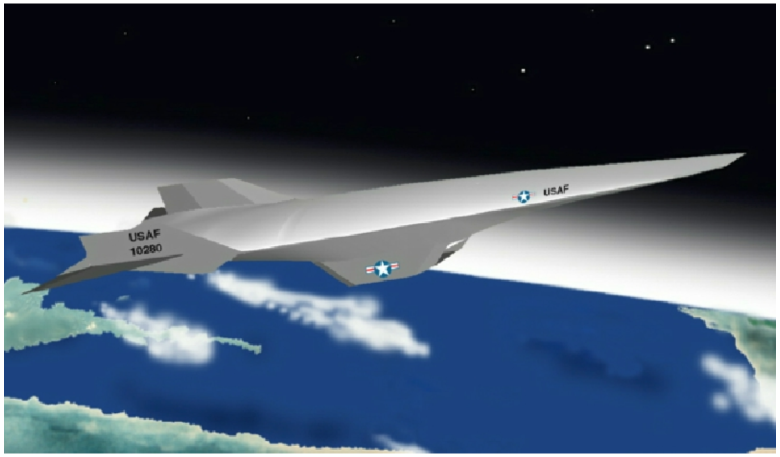
Developing Technologies for the Future

"USAF will aggressively pursue emerging technologies to develop, field, and operate UAV solutions….based on cost, capability, reliability, and suitability."--*consolidated end state AF Long-Range Plan*

Space Operations Vehicle System

Assure cost effective and rapid access to space via:

- Affordable launch on demand
- Reusable, long-life vehicles
- Fast turn-around
- High sortie rate
- Aircraft-like operations

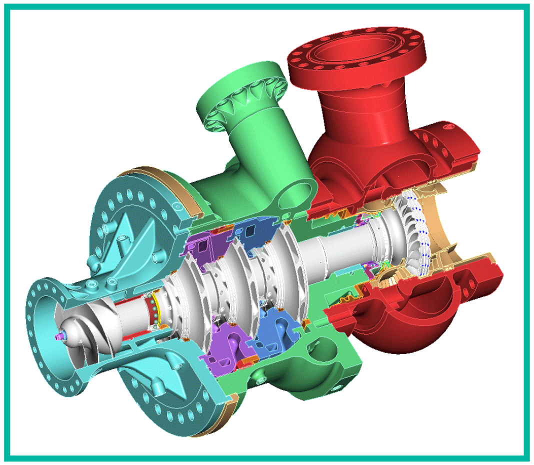


THE WAY AHEAD is through increased operability via improved structures/materials, more efficient thermal protection systems, enhanced propulsion systems, & flight controls

LIQUID ROCKET TURBOPUMP INLET AND MAIN PUMP HOUSINGS

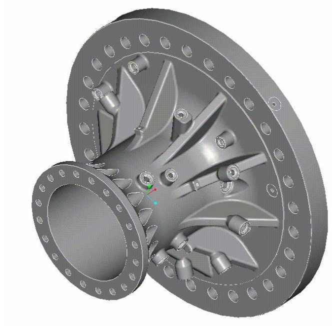
STATUS: ***In Development***

SELECTION CRITERIA:
- high specific strength
- compatibility with high pressure liquid and gaseous hydrogen and/or liquid and gaseous oxygen
- 3–6% ductility at –252°C
- castable to complex shape
- low cost



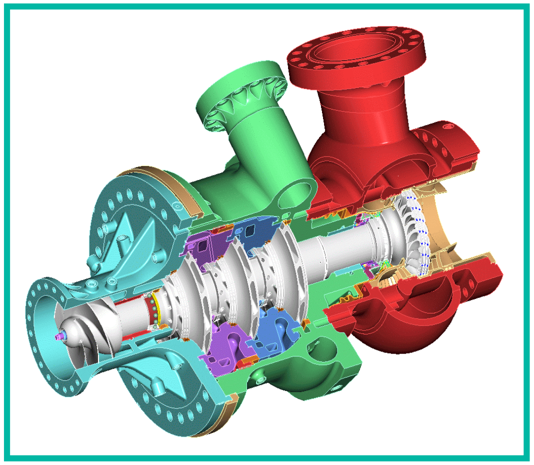
MATERIAL:
- current material is cast IN718 for high pressure pumps, and A357 for low pressure pumps

BENEFITS:
- 30% weight reduction over cast IN718



COMMENTS:
Pump motor housings for liquid hydrogen and liquid oxygen comprise a significant fraction of a typical liquid propellant rocket engine weight. A 30% weight reduction provides significant improvements in thrust-to-weight and payload to orbit. Al alloys possess excellent compatibility with liquid and gaseous hydrogen.

LIQUID ROCKET TURBOPUMP INDUCER AND IMPELLER



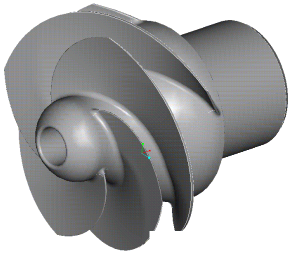
STATUS: ***Proposed Application***

SELECTION CRITERIA:

– very high specific strength
– compatibility with high pressure liquid and gaseous hydrogen and/or liquid and gaseous oxygen
– 3–6% ductility at –252°C
– affordable manufacturing to complex shape

MATERIAL:

– current material is Ti-5Al-2.5Sn



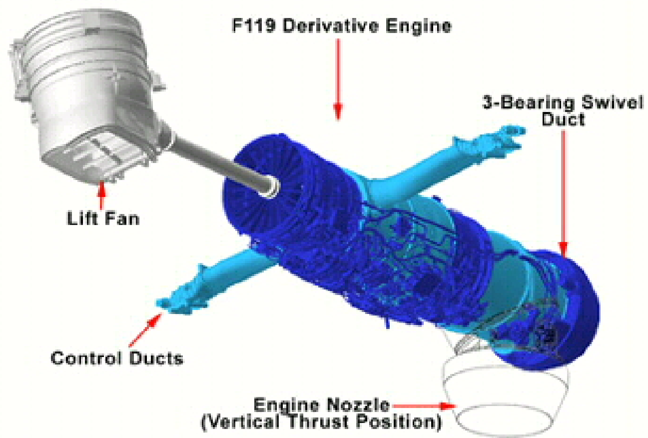
BENEFITS:

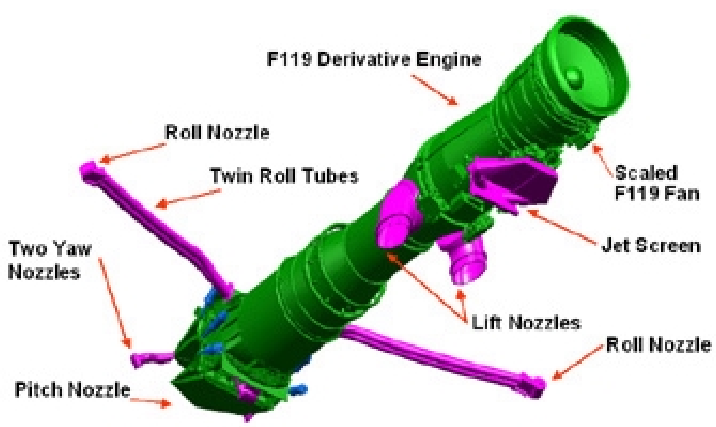
– enables higher rotational speed for improved performance
– enables reduction in engine size, significantly decreasing engine weight

COMMENTS:

Current inducer and impeller rotational speeds are limited by material strength. A material with higher specific strength can enable higher rotational speeds. This can either increase thrust for a given engine mass, or can provide equivalent thrust at a reduced engine mass by reducing the pump diameter.

JOINT STRIKE FIGHTER





C–17 ENGINE PYLON FRAMES AND WING FLAPS

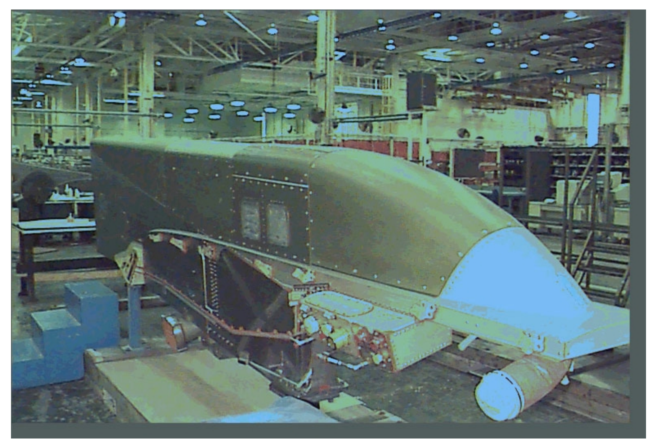
STATUS: ***Projected Applications***

SELECTION CRITERIA:
- low cost compared to Ti alloys
- specific stiffness and strength equivalent to Ti alloys
- full life operation at temperatures up to 190°C (375°F)

MATERIAL:
- current materials are Ti alloys

BENEFITS:
- reduced acquisition costs compared to Ti baseline

COMMENTS:
These parts are currently produced from Ti alloys to accommodate operation temperatures of up to 190°C (375°F). Thus, the specific strength and stiffness of candidate materials will need to compete with Ti alloys at these temperatures. Thermal loads are imposed by conduction from the engine or by wash from the hot exhaust gases. Significant acquisition cost savings and lead time reductions are projected by replacement of Ti alloys. Candidate materials must be available in sheet form (wing flaps) or bulk form (pylon frames) to be considered.



C–17 STRAKE FINS, WINGLETS

STATUS: ***Projected Applications***

SELECTION CRITERIA:

- low cost compared to graphite/epoxy
- high specific stiffness
- availability in sheet form

MATERIAL:

- current material is graphite/epoxy

BENEFITS:

- reduced acquisition and maintenance costs compared to graphite/epoxy baseline
- improved supportability

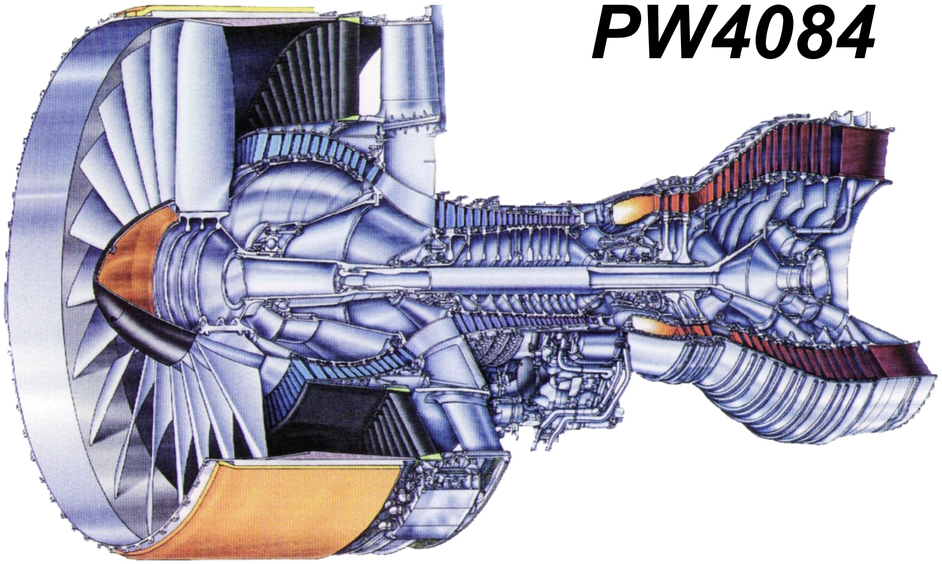
COMMENTS:

These parts are currently produced from graphite/epoxy. Significant acquisition cost savings and improved supportability (battle damage repair, stripping, painting, etc.) are projected by replacement with metallic material. The parts are large (the strake fin is nearly 5 meters (16 feet) long, and the winglet is over 2.5 meters (8 feet) high. Thus, candidate materials must be available in wide sheets to be a consideration. The specific strength and stiffness of candidate materials will need to compete with cross-plied graphite/epoxy.

GAS TURBINE ENGINES

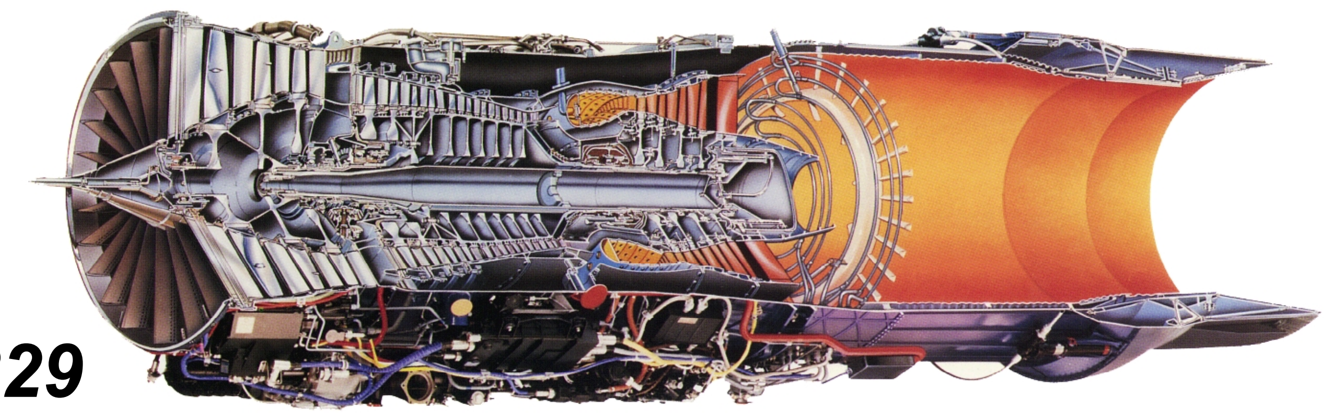
AF Research Laboratory / Materials and Manufacturing Directorate — Metals, Ceramics, and NDE Division

PW4084



Applications

- LPC stators
- HPC stators, shrouds
- HPC case
- rings
- fan case



F100-PW-229

Structural Amorphous Aluminum

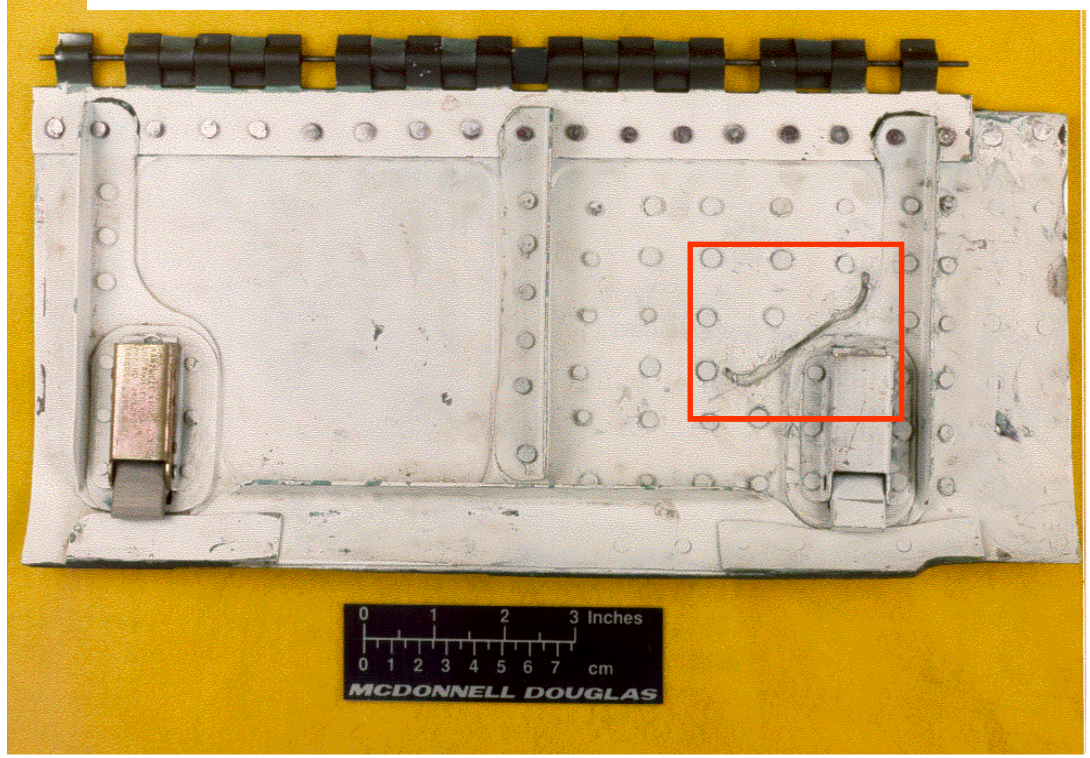
Weight-Critical Rotorcraft Structures Are Driving The Use Of Advanced Metallics

Comanche Has 58 Aluminum-Beryllium Components For Support Structures In Its Electro-Optical Sensor System

Composite Skins Are Widely Used To Minimize Weight

Structural Amorphous Aluminum

Prematurely Cracked F-15 Door Skin
Due To Unanticipated Buffet Loads



POTENTIAL AEROSPACE APPLICATIONS

AIRCRAFT

F-15, F-22	Upper aft fuselage panels
F-15, F-22	Upper aft fuselage skins
F-15, F-22	Keel sections
F-15, F-22	Frames and bulkheads
F-15, F-22	Longerons
F-22	Keel
F-15, F-22	Stiffeners
F-15	Vertical stabilizer rudder
C-17	Engine pylon skins
C-17	Engine pylon frames
C-17	Stiffeners and clips
C-17, F-15	High temperature panels
JSF	Aft exhaust doors
JSF	Lower aircraft skins
F-16	Bonded honeycomb flaperons
F-16	Fixed trailing edge panel
F-16	Leading edge flap
F-16	Spar ribs and fittings
F-16	Spar closure unit
B-1	Bungee wedge linkage
F/A-18	Forward barrel lower longeron
F/A-18	Aft fuselage nozzle fairing skin
F/A-18	Dorsal tank fuel access doors
F/A-18	Center fuselage engine bay doors
F/A-18	Center fuselage bleed plates
ABL	Optical turret drive gear
ABL	Laser subsystem fwd optical bench

AERO PROPULSION

F-119, JSF Engine	Stators
F119 Engine	Fan case
4XXX Engines	Fan case stator vane
4XXX Engines	Shrouds

SPACECRAFT

Satellites	Tube fittings
Satellites	Bonded honeycomb panels
Satellites	Cylinders
Positioning satellites	Deployable structures
Mechanical systems	Gimbals, hinges

MISSILES

AIM-120, AMRAAM	Wing restraint (4 per missile)
AIM-120, AMRAAM	Guidance fins (4 per missile)
AIM-120, AMRAAM	Wing
AIM-9X	Wing, fin, seeker nose cone

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AMORPHOUS AL CHARACTERISTICS

Composition

- Al base (>80%), with additions of transition metals, rare earth metals

Microstructure

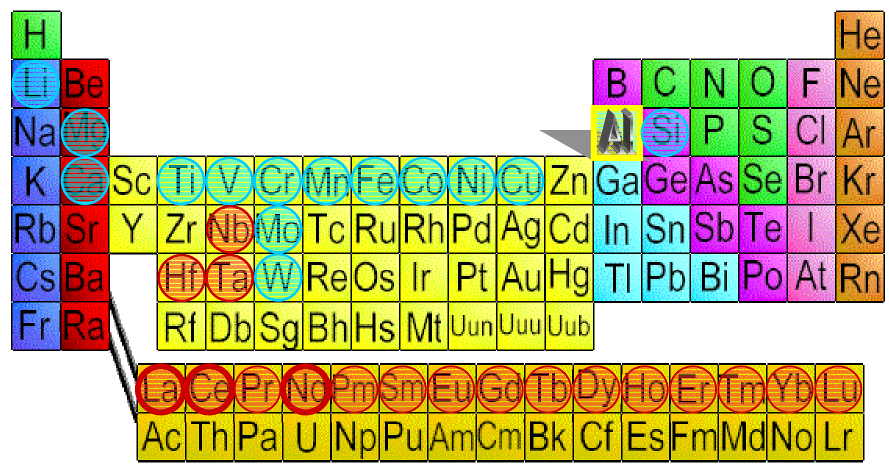
- the ultimate solid solution
- controlled crystallization produces dispersion of crystalline or quasicrystalline phases

Processing

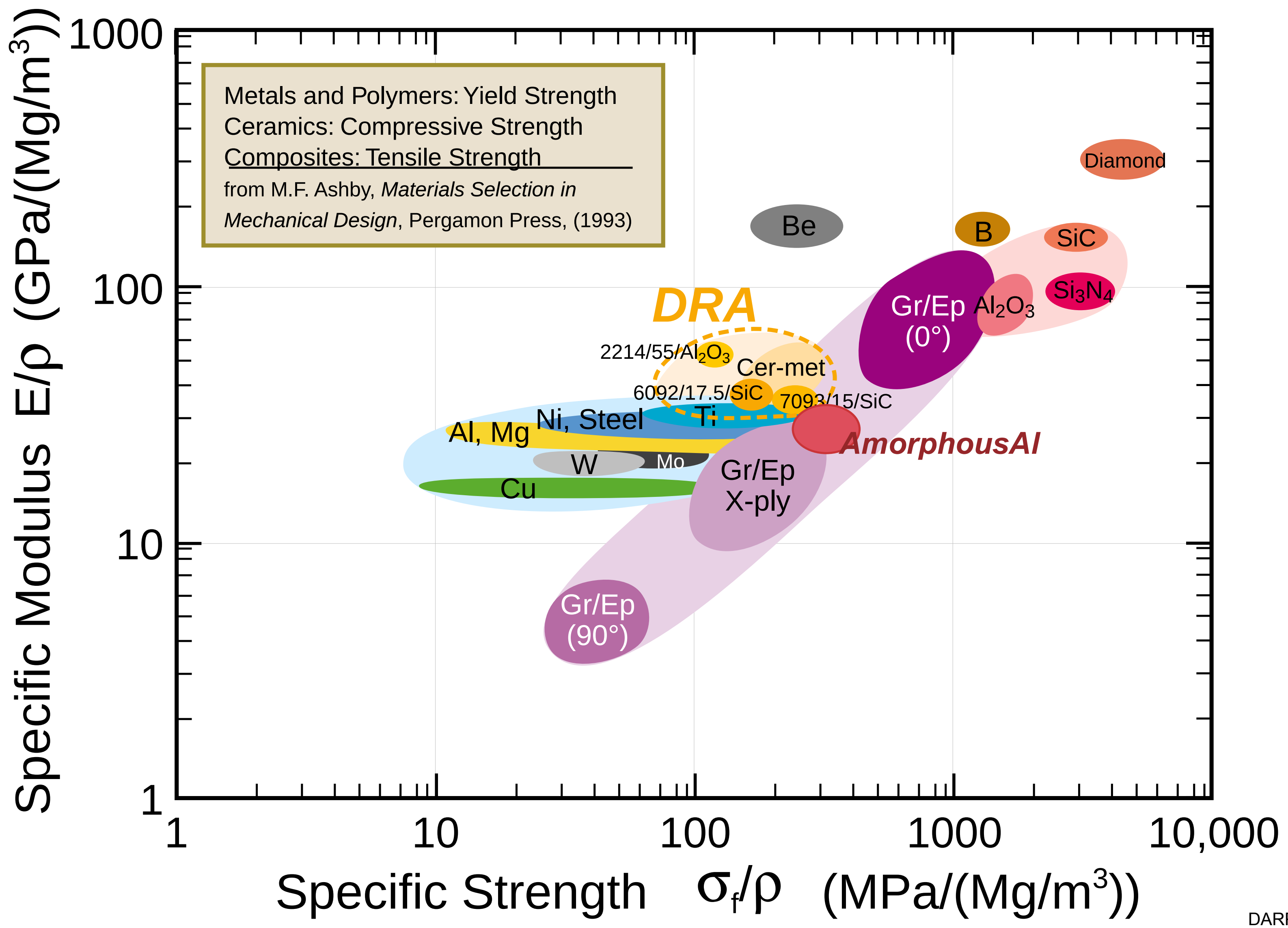
- controllable glass-forming ability, crystallization
- excellent deformation under constrained conditions

Properties

- exceptional specific strength
- isotropic properties
- metallic behavior
- unusual corrosion behavior



SPECIFIC PROPERTIES



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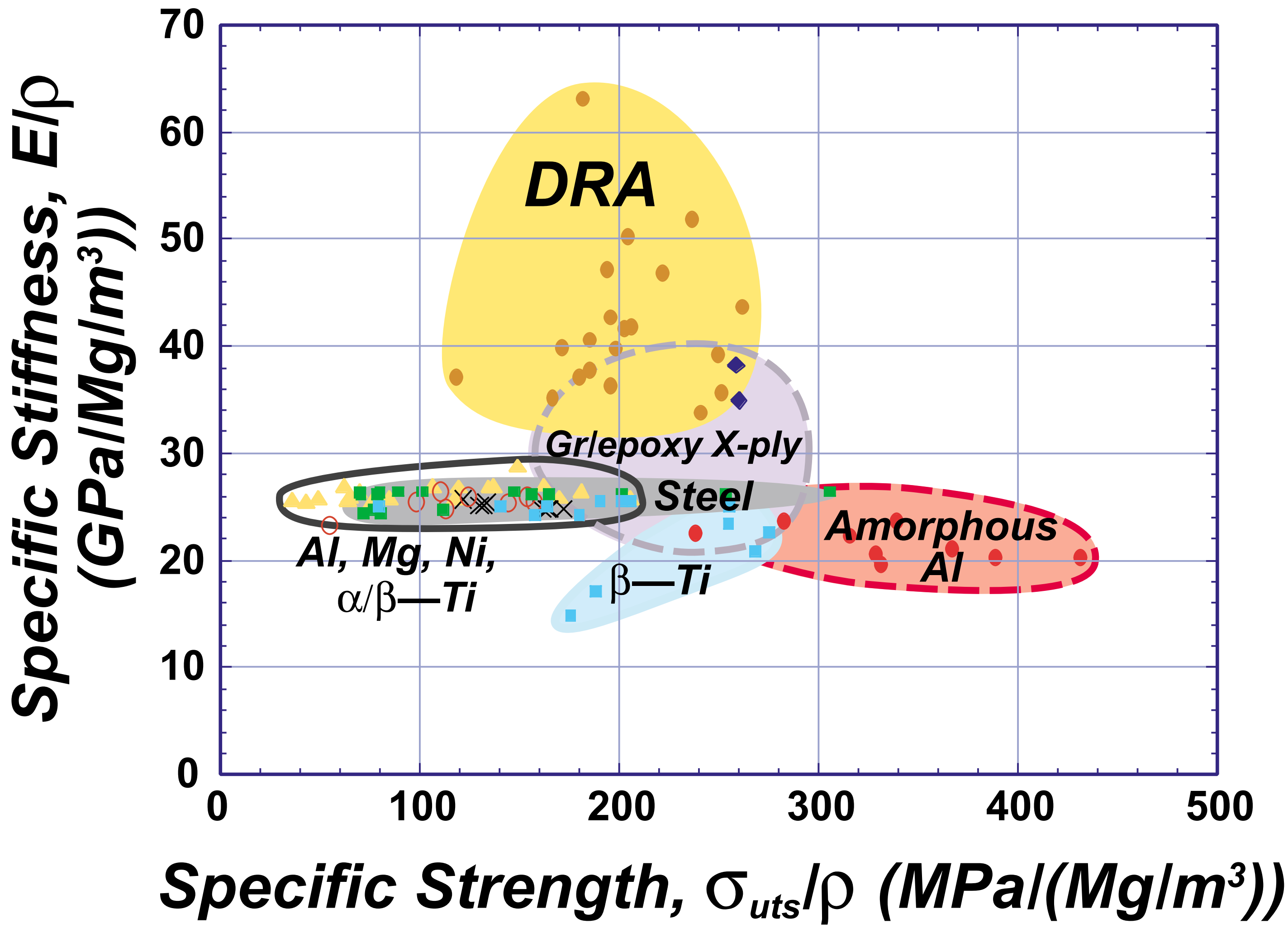
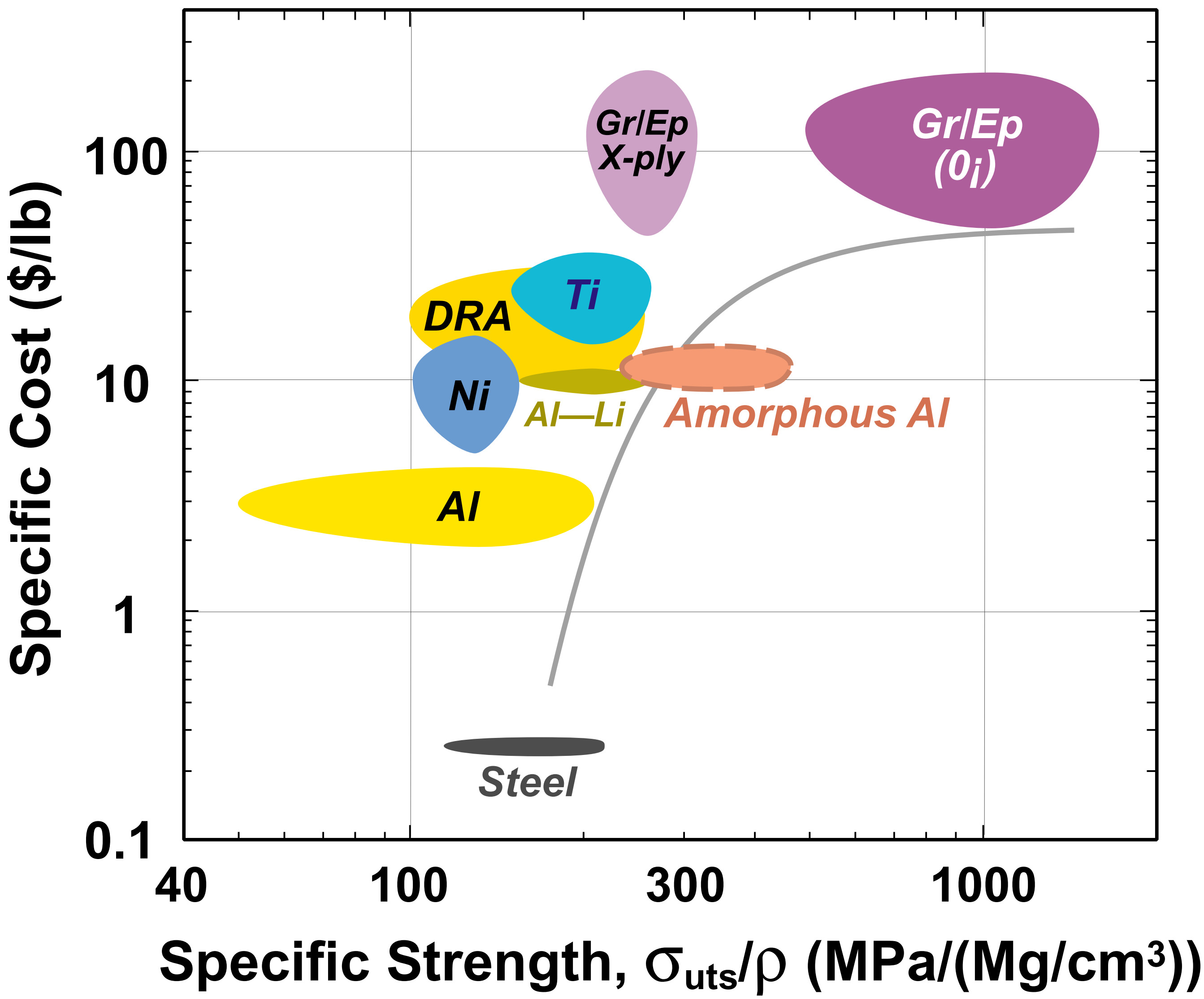


Metals data from Metals Handbook, Desk Edition, 2nd Edition, ASM International
Graphite/epoxy data from M.F. Ashby, Materials Selection in Mechanical Design, Pergamon Press, 1992

SPECIFIC COST vs SPECIFIC STRENGTH OF ENGINEERING MATERIALS



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TECHNOLOGY ISSUES

Explore composition space

– balance compositions which provide adequate:
  - ✓ glass-forming ability
  - ✓ crystallization temperature
  - ✓ obtainable microstructures
  - ✓ physical and mechanical properties
  - ✓ cost

Establish processing methodologies

– define primary and secondary processes which can provide amorphous structure in usable product forms

Microstructure

– explore range of unique microstructures achievable

– ensure adequate microstructural stability is retained

Mechanical properties

– provide damage tolerance along with exceptional strength

– provide improvement in specific stiffness

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CONCLUDING REMARKS

DoD emphasis on high temperature aerospace materials now being joined by requirements for high specific strength and stiffness and affordability

– configuration of future systems will be controlled by these material characteristics

A broad range of AF systems require materials with exceptional specific strength and stiffness

– space systems
– current and future aeronautical systems
– sustainability of existing fleet

Amorphous Al provides affordable metallic material approach for achieving exceptional specific properties